BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: An Open Loop Crew-Monitored LM Descent - Case 310

DATE: March 26, 1968

FROM: F. Heap

ABSTRACT

As part of a study to determine the feasibility of reducing the Apollo guidance computer memory to half its present size, a simple open loop LM descent scheme was postulated and examined. The scheme is considered minimal in terms of capability and safety; it would require much increased crew and RTCC participation. It has utility, however, in providing an example against which the relative superiority and memory cost of a simplified explicit guidance closed loop system could be measured.

A trajectory was designed to follow the scheme; final approach and landing constraints could be met, considering 3σ altitude errors and reasonable flight path errors at Hi Gate. The ΔV cost above the current budget could be about 190 ft/second.

Many factors which might qualify the results were not considered. No estimate of the computer word count was made.

(NASA-CR-95423) AN OPEN LOOP CREW-MONITORED LM DESCENT (Bellcomm, Inc.) 10 p

N79-71857

Unclas
00/13 11144

FF No. 602

CR-95423
(NASA CR OR TMX OR AD NUMBER)

(CATEGORY)

[redacted]

BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: An Open Loop Crew-Monitored LM Descent - Case 310

DATE: March 26, 1968

FROM: F. Heap

MEMORANDUM FOR FILE

INTRODUCTION

As part of the study to determine the feasibility of reducing the Apollo guidance computer memory to half its present size (Reference 1), a simple open loop LM descent scheme was postulated and examined. The scheme is considered to be minimal in terms of capability and safety; it would require much increased crew and RTCC participation. Because of these factors, it may be found wanting on further investigation. It has utility, however, in providing an example against which the relative superiority of a simplified explicit guidance closed loop system can be measured.

BASIC SCHEME

Under the simplified open loop scheme, the LM is inserted into the Hohmann descent transfer orbit by firing the descent engine to apply the necessary ΔV in a fixed vehicle attitude. The ΔV, attitude, and time of ignition are computed by the RTCC, based on the lunar parking orbit elements and the position of the landing site.

The ignition point for powered descent is at a fixed range (central angle) from the landing site. There is a nominal ignition time based on a pre-targeted reference trajectory. The RTCC evaluates the transfer orbit, based on tracking and insertion telemetry, and updates the ignition time and the powered descent parameters based on a real-time retargeting, if necessary.

The braking phase is at near-full throttle thrust to Hi Gate with constant pitch rate from an initial pitch attitude. Minor ($\pm$3%) throttle capability is required to adjust the thrust to the nominal, in face of thrust errors. (In the current descent, the engine operates only at full throttle or below 58% thrust. Recent investigations by MSC have explored the feasibility of adjusting the throttle to eliminate the expected $\pm$2-1/2% thrust error.) This throttle capability requires a simple regulator function in the computer.

Neglecting for the moment downrange and crossrange errors, which will be addressed later, the major uncertainty at ignition is altitude, which propagates to an altitude error and second order flight path error at Hi Gate. The criterion for Hi Gate is a fixed total velocity magnitude. The crew monitors the landing radar output and estimates the altitude and flight path errors. The altitude error at Hi Gate is currently estimated to be 5500 feet (3σ) based on previous MSC studies where landing radar updates were suppressed. For this study, the flight path angle error has been assumed to be not more than $\pm 1°$. During the last minute of the braking phase, the computer uses a simple algorithm to determine time to go to Hi Gate and to estimate the altitude and flight path angle at Hi Gate, using inertial data corrected by the crew's estimate of the difference between inertial data and radar data. To eliminate smoothing and data handling requirements in the computer, actual radar data is not used.

At Hi Gate the computer determines and commands the final approach phase pitch angle and thrust acceleration. The final approach phase has a constant flight path angle, with constant pitch attitude, constant thrust acceleration and essentially constant look angle. Figure 1a shows the profile of the final approach phase schematically. Because altitude errors are not eliminated by radar updates, altitude errors propagate into downrange errors as shown, increasing the landing ellipse downrange dimension from the currently estimated downrange dispersion of 25,000 feet to 37,500 feet. Crossrange error is not affected. The phase has nominal values of the control constants, pitch angle and thrust acceleration, to give a look angle (angle from the negative x body axis to the line of sight to the landing site) of say 40 degrees (site 15 degrees above the window bottom). The effect of errors in altitude and flight path angle at Hi Gate is to modify the control constants. The nominal trajectory is chosen so that, even with maximum errors, thrust remains less than maximum throttleable thrust and look angle is more than 25 degrees.

Lo Gate is chosen to be at altitude 500 feet, with horizontal and vertical velocities within the crew requirement range. The landing phase is flown manually.

FINAL APPROACH PHASE DYNAMICS

Using a flat moon approximation, the equations of motion of the LM in the vertical plane are

$$\dot{V} = -\frac{T}{M}\sin(\theta-\gamma) - g\sin\gamma \tag{1}$$

$$V\dot{\gamma} = \frac{T}{M}\cos(\theta-\gamma) - g\cos\gamma \tag{2}$$

where the symbols are as illustrated in Figure 1b.

For a constant flight path, γ = constant, $\dot{\gamma} = 0$, so Equation (2) yields

$$\frac{T}{M} = \frac{g\cos\gamma}{\cos(\theta-\gamma)} \tag{3}$$

$\theta-\gamma$ is the complement of the look angle, so constant θ gives constant look angle and thrust acceleration.

Substituting into (1),

$$\dot{V} = g\,(-\cos\gamma\,\tan(\theta-\gamma) - \sin\gamma). \tag{4}$$

For constant pitch angle and flight path angle, $\dot{V}$ is also constant. Denoting S as distance along the flight path and h as altitude, $\dot{V}$ can be written as

$$\dot{V} = \frac{VdV}{dS} = \frac{VdV}{dh}\sin\gamma \tag{5}$$

then

$$g(-\cos\gamma\,\tan(\theta-\gamma) - \sin\gamma)\,dh = VdV\,\sin\gamma \tag{6}$$

Integrating from h_o, V_o (Hi Gate) to h_D, V_D (Lo Gate) gives

$$g(-\cos\gamma\,\tan(\theta-\gamma) - \sin\gamma)\,(h_o - h_D) = \tfrac{1}{2}(V_o^2 - V_D^2)\sin\gamma \tag{7}$$

$$\theta-\gamma = \arctan\left\{-\tan\gamma(1 + (V_o^2 - V_D^2)/2g(h_o-h_D))\right\} \tag{8}$$

Equations (8) and (3) yield the controls θ and T/M. given the initial Hi Gate conditions (V_o, h_o, γ) and the desired Lo Gate conditions (V_D, h_D). For the computer, they can be written as

$$\theta = \gamma + \arctan\left\{-\tan\gamma(1 + k_1/(h_o-k_2))\right\} \tag{9}$$

$$T/M = k_3\,\cos\gamma/\cos(\theta-\gamma) \tag{10}$$

where the k's are fixed computer constants.

TRAJECTORY SIMULATION

The validity of the postulated scheme and its capability to perform a landing within certain mandatory constraints were tested by conducting two simulations. The constraints are:

1. The line of sight to the landing site should be above the window bottom during the final approach phase. This means that the look angle, 90 - (θ - γ), should be greater than 25 degrees approximately, as the bottom of the window is 25 degrees from the negative T/M axis.

2. The descent engine thrust should be less than 58% (6090 lbs.) during the final approach phase. This means that T/M should be less than 10.5 ft/sec^2 approximately (assuming LM weight of 18,500 lbs. in the final approach phase).

3. The Lo Gate conditions should be within the range to allow for a switch to manual control for the landing phase. For a Lo Gate altitude of 500 feet, the vertical velocity should be less than 17 ft/sec., and the horizontal velocity should be less than 60 ft/sec. (Reference 2)

For the first simulation, the flight path angle (γ) was chosen at -15 degrees, giving a Lo Gate velocity (V_D) of 65.5 ft/second (equal to 17/sin 15°). The nominal look angle was chosen to be 40 degrees ($\theta - \gamma = 50°$). Hi Gate altitude (h_o) was chosen to be 9500 feet, similar to that in the current reference trajectory (Reference 3). Hi Gate velocity (V_o) was found, by inverting Equation 8, to be 577 ft/sec. Equations (8) and (3) were then used to determine the variation in look angle and thrust acceleration required for 3σ off-nominal altitudes ($\pm$1°) at Hi Gate. The results showed that for an off-nominal descent in which the Hi Gate altitude was 3σ low at 4000 feet, the resulting line of sight to the landing site in the final approach phase was below the window bottom (look angle <25 degrees) and the thrust acceleration required a thrust in excess of 6090 lbs. A BCMASP (Bellcomm Apollo Simulation Program) targeting run indicated that, for a 3σ high altitude error at Hi Gate, the ΔV cost was about 300 feet per second greater than that for a no-error trajectory.

For the second trajectory, the Hi Gate altitude was increased to 12,500 feet (intuitively) to correct the off-nominal look angle and thrust acceleration excesses. At the same time the flight path angle was changed (intuitively) to -20 degrees to maintain a tolerable increase in ΔV cost for the 3σ high altitude case. Lo Gate velocity was 46.8 ft/sec. (= 17/sin 20°);

Hi Gate velocity was 540 ft/sec. Nominal look angle was kept at 40 degrees. The results are shown in Figure 2. The look angle remains above the window bottom for all off-nominal altitudes and flight path angles. The thrust acceleration only exceeds the 6090 lb. thrust level at the lowest extreme of the expected altitude range. (It is probable that if necessary this constraint could be eased slightly.) The maximum ΔV penalty is 295 ft/sec. above the no-error case.

Figure 3 is a ΔV summary, comparing the ΔV requirements for this descent with those in the standard ΔV budget (Reference 4). The total descent budget for the latter is 7180 ft/sec. Because of the arbitrary way in which the conditions for the postulated descent were chosen, it is possible that the 190 ft/sec. ΔV penalty could be lowered by a judicious choice of Hi Gate altitude and flight path angle.

LIMITATIONS

This study was performed without considering many factors which could qualify the results. Among these are digital autopilot accuracy, RCS usage to achieve the constant pitch rate, ΔV required to correct for residual altitude and velocity errors at Lo Gate, crew capability to monitor the descent and assess the performance, increased landing site dimension, aborts from the descent, and safety. No estimate of the computer word count was made.

SUMMARY

A simple open loop LM descent scheme was postulated and examined. A trajectory was designed to follow the scheme; final approach and landing phase constraints could be met, even if 3σ altitude errors and 1° flight path angle errors at Hi Gate were considered. ΔV cost above the current budget could be about 190 ft/sec. The scheme would require much increased crew and RTCC participation. Many factors which might qualify the results were not considered.

F. Heap

2013-FH-wcs

Attachments
Figures
1, 2, & 3

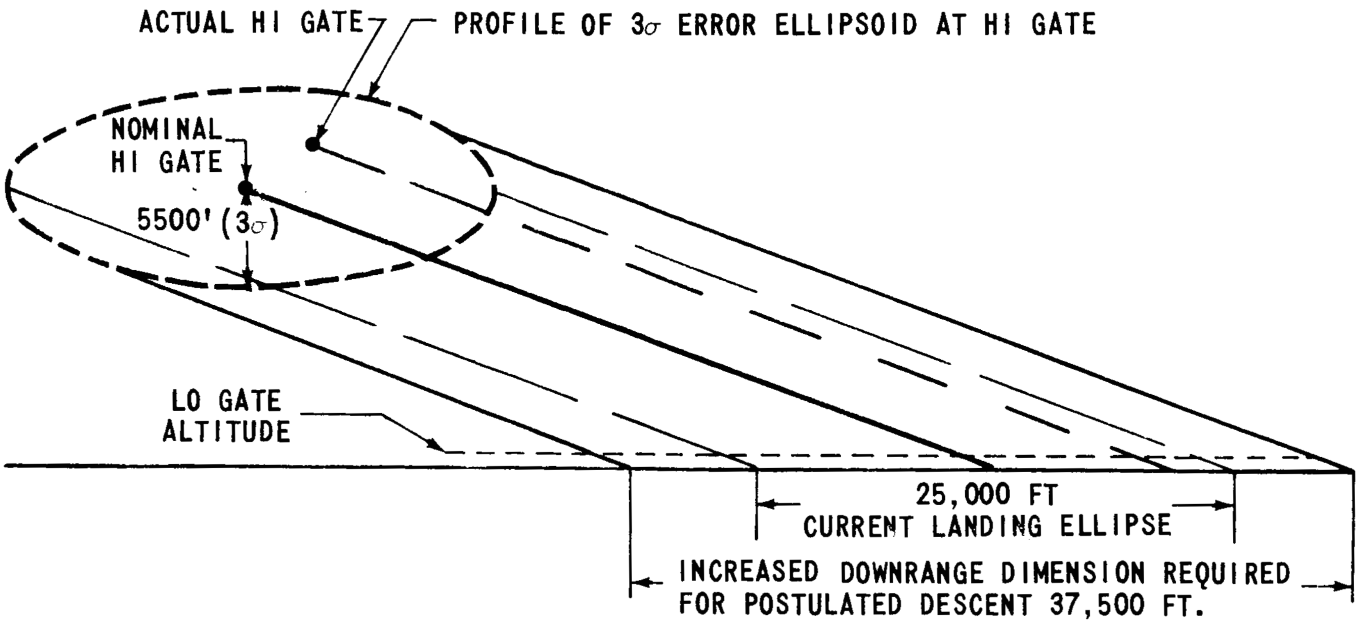
REFERENCES

1. Letter to Dr. R. R. Gilruth from Dr. G. E. Mueller, February 14, 1968.

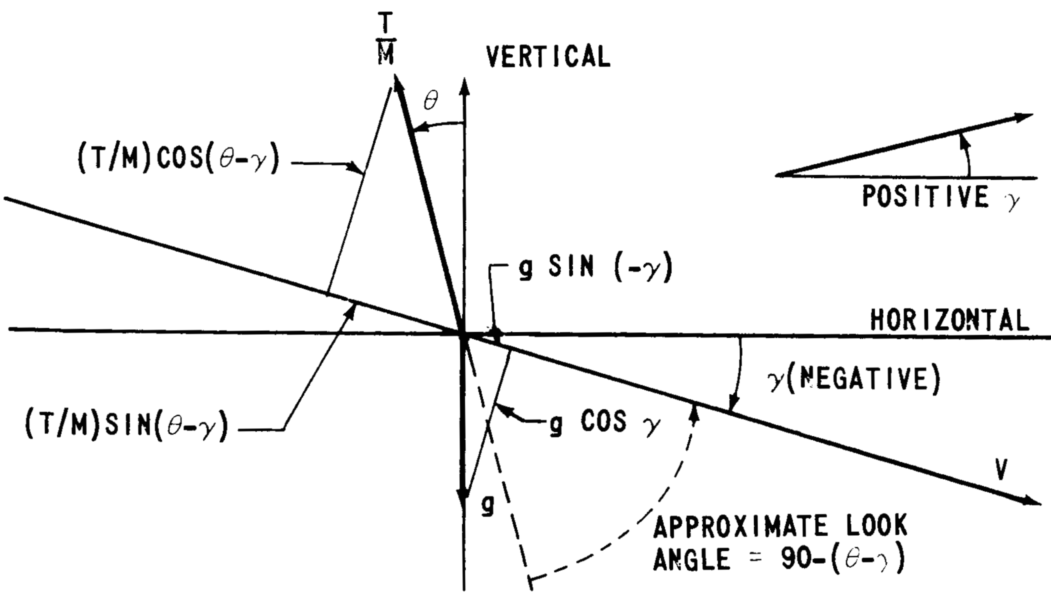
2. Trajectory Constraints to be Used in Design of Guidance Equations for the Region Between Hi Gate and Hover Aim Point. W. R. Kelly, MSC Memorandum EG27-72-67.

3. Proposed LM Powered-Descent Trajectory for the Apollo Lunar Landing Mission. W. M. Bolt and F. V. Bennett. MSC Internal Note 67-FM-117.

4. Revised LM Descent and Ascent ΔV Budgets for the Lunar Landing Mission. F. V. Bennett, MSC Memorandum 67-FM9-15.



a) LM FINAL APPROACH PHASE



ALONG THE FLIGHT PATH:

$$\dot{V} = -(T/M)\,\mathrm{SIN}(\theta-\gamma) - g\ \mathrm{SIN}\ \gamma$$

NORMAL TO THE FLIGHT PATH:

$$V\dot{\gamma} = (T/M)\,\mathrm{COS}(\theta-\gamma) - g\ \mathrm{COS}\ \gamma$$

b) LM DYNAMICS (FLAT MOON)

FIGURE I

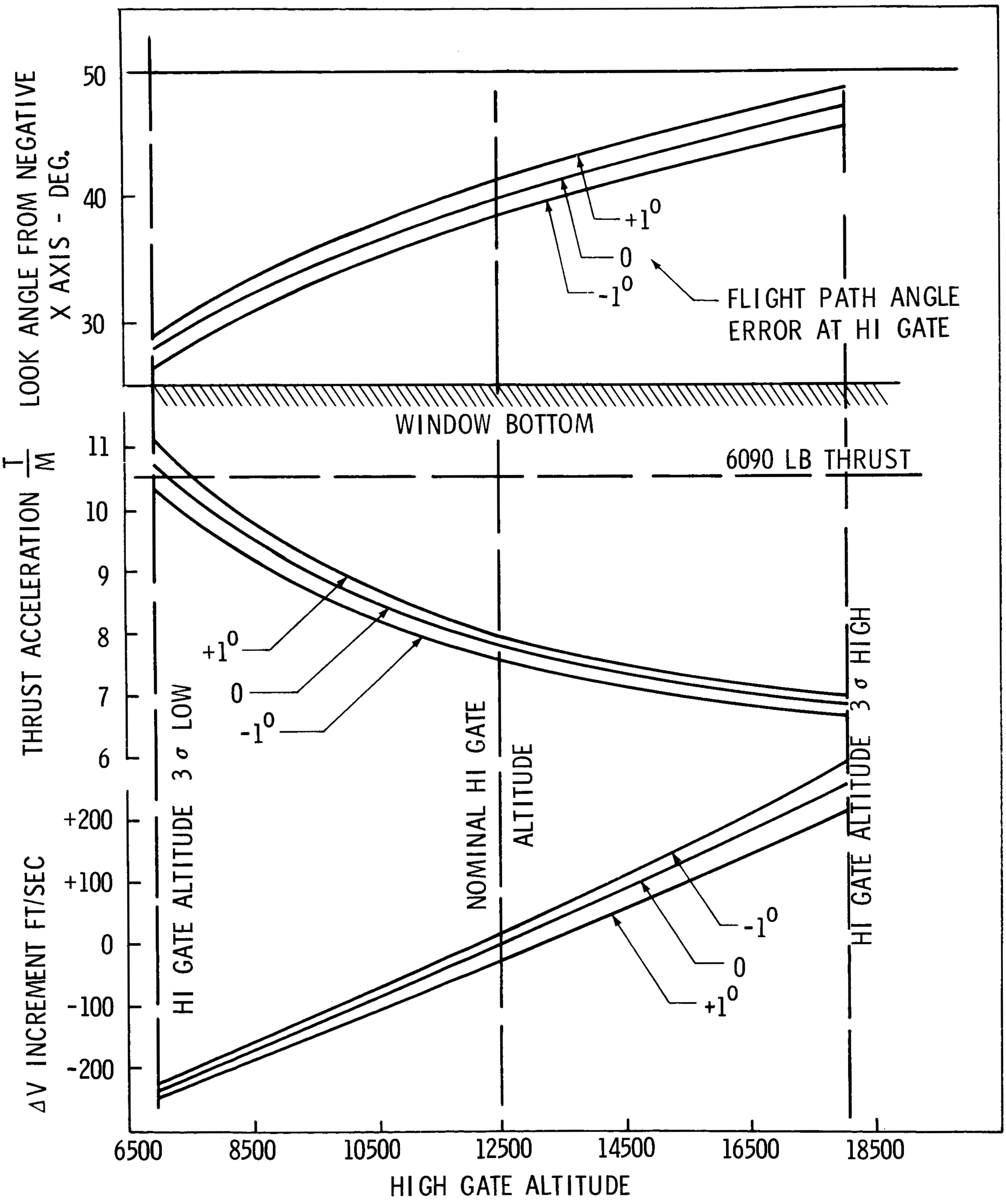


FIGURE 2 - LM FINAL APPROACH PHASE CHARACTERISTICS AND CONSTRAINTS

	PRESENT* DESCENT	POSTULATED DESCENT	ADDED ΔV
BRAKING	5345	5245	-100
FINAL APPROACH	866	915	+ 49
DPS THRUST VARIATION	40	0	- 7**
NAV. AND TERRAIN UNCERTAINTY	40	0	- 7**
LPD OPERATION	60	20	- 40
HI GATE ALTITUDE 3σ HIGH	--	295	+295***
		TOTAL	+190

*MSC MEMO 67-F M 9-15

**RSS'D WITH OTHER DISPERSIONS IN CURRENT BUDGET

***CONSERVATIVE, NOT INCLUDED AS RSS

FIGURE 3 - LM DESCENT ΔV SUMMARY

BELLCOMM, INC.

Subject: An Open Loop Crew-Monitored LM Descent - Case 310

From: F. Heap

Distribution List

Copy to
Messrs. D. R. Anselmo
A. P. Boysen, Jr.
G. L. Bush
J. O. Cappellari, Jr.
D. R. Hagner
W. G. Heffron
B. T. Howard
D. B. James
J. L. Marshall, Jr.
J. Z. Menard
V. S. Mummert
V. L. Osborne
P. E. Reynolds
I. M. Ross
R. V. Sperry
R. L. Wagner
Division 103
Department 1023
Central Files
Library